THREE DIMENSIONAL KINEMATIC DIFFERENCES BETWEEN MALE AND FEMALE SOCCER PLAYERS

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This research describes a method of biomechanical analysis that allows for kinematic data to be captured in a game-like environment and key biomechanical differences between male and female soccer players to be identified. Male (n=3) players aged between 22 and 24 years and female players (n=3) aged between 19 and 23 years were recorded using a VICON motion capture system operating outdoors at an artificial grass venue. Biomechanical measurements of the lower limb such as inversion/eversion and flexion/extension of the ankle; the flexion/extension, varus/valgus and internal/external rotation of the knee; and the internal/external rotation and abduction/adduction of the hip, were recorded. Initial observations showed an increase in knee valgus and external tibial rotation in female players' key activities performed during a soccer game.

KEYWORDS: 3D motion capture, leg kinematics, ACL injury.

INTRODUCTION: Biomechanical analysis using three-dimensional (3D) motion capture has been widely used to accurately track athlete motion for performance and injury prevention applications (Alderson 2015). 3D motion capture is often utilised to understand lower limb kinematics of soccer players to help minimise injury risk. This research will use 3D kinematic analysis of male and female players to observe whether any biomechanical differences during non-contact movements could lead to an increased risk of injury for either gender. The anterior cruciate ligament (ACL) is the most frequently injured single ligament in the knee associated with a limited range of motion (Ireland 1999). A tear to the ACL can leave individuals with a significant economic cost, a lengthy rehabilitation process and an increased risk of osteoarthritis. The risk of ACL injury is experienced more by female athletes as they are 2.3 times as likely to experience an ACL tear when compared to male players. In Australia, soccer saw an 11% increase in female participation between 2018 and 2019 (Johnson 2020). Despite this increase in female participation rates and increased risk of serious injury, the analysis of a broad range of female player movements remains limited within the literature.

It has been reported that 70-80% of ACL injuries occur during non-contact situations such as plant-and-cut movements, change of direction, deceleration from high speed or a hyperextension of the knee upon landing from a jump (Mansfield & Bucinell 2017).

While previous literature has focussed on single movements such as changes of direction (Landry et al. 2007), kicking (Sakamoto et al. 2013) and jumping (Smith et al. 2007), there is limited literature that employs a holistic approach to determine kinematic differences between male and female players over the range of motion that occurs within a soccer game. The aforementioned studies utilised motion capture software to analyse the position and kinematics of the players' lower limbs. In these studies, the motion capture system was set up in an indoor environment, with Thomas et al. (2020) opting to use an indoor, artificial grass track as opposed to a traditional laboratory floor utilised by other researchers.

The present study sought to apply biomechanical analysis to a game-like environment using 3D motion capture and in-sole pressure measurements. While it is easier to operate a motion capture system indoors, biomechanical testing should be performed in an environment in which the athlete plays to ensure movements are as realistic as possible. To provide this environment, the camera settings on the motion capture system were altered so that they could function in a naturally lit environment. The force platform used in previous biomechanical studies was replaced with an in-sole pressure pad so that athletes could experience an unrestricted range of motion. The data collected from the pressure pad will be used in future studies to estimate the anterior-posterior and medial-lateral forces exerted on the knee that can lead to potential ACL injury.

METHODS: Three male soccer players (1.84±0.04m, 78±11kg, 23±2 years old, 12±3 years playing experience) and three female soccer players (1.60±0.13m, 65±11kg, 21±2 years old, 12±5 years playing experience) volunteered to participate in this study by giving their informed consent. The University of Adelaide Human Research Ethics Committee provided ethics approval. Testing was undertaken at a soccer club on an artificial grass playing surface which consisted of a 'Soccer Pro Max S' turf with both a 'Sandball' sand infill as well as a thermoplastic elastomer infill. Each participant was required to be within the age of 18-25 years, have a minimum of 5 years of playing experience at a club level as well as no previous injuries to their ACL in either leg. Kinematic data was recorded using a 12 camera VICON motion capture system (VICON, Oxford, UK) operating at 100Hz, coinciding with the sampling frequency of plantar pressure data collected by a TekScan F-Scan in-sole pressure pad (TekScan, Boston, USA). Sixteen 14mm reflective markers were attached to each participant's lower limbs as per the VICON Plug-In-Gait marker set (Vicon Motion Systems 2016). Hamill and Selbie (2004) warn against using three individual non-collinear markers due to the inaccuracy caused by an independent marker; instead, two three-marker clusters were applied to each leg in place of thigh and tibia markers. Players performed calibrations and initial kicking tests to ensure marker placement would not interfere with movement. In order to capture the plantar pressure used in future research, a portable TekScan F-Scan system was inserted into each player's boot. This allowed for complete freedom of movement of the player as they did not have to strike a particular area of the testing surface.

To perform an outdoor motion capture analysis, the aperture and shutter speed for each camera needed to be monitored before each test to ensure the amount of natural light the cameras were detecting was minimal (Bernadina et al. 2019). This required a manual check of each camera's capture volume and complete system calibration before each test subject due to the inconsistent natural light. While skin artefact motion poses a greater threat to the accuracy of motion capture results, incorrect camera settings would cause the motion capture system to detect reflections from the surrounding environment as markers, severely increasing processing time. To ensure consistency of the results, a 'World Error' of less than 0.6 (approximately 2mm in the testing environment) was required for each calibration.

The players were required to perform each of the following actions four times: a straight-line run, a run and stop, a run and pivot, a plant-and-cut movement, a jump, a pivot landing from a jump (jump exit) as well as kicking a ball with both the side and the instep of the boot. These actions were chosen due to frequent occurrence during a soccer game as well as their likelihood of causing an increase in ACL load (Ireland 1999).

Data was processed and then analysed using VICON ProCalc to determine joint angles and 3D kinematics. Kinematic values such as inversion/eversion and flexion/extension of the ankle; the flexion/extension, varus/valgus and internal/external rotation of the knee; the internal/external rotation and abduction/adduction of the hip, were recorded as well as the velocities and accelerations of the femur, shank and foot for the heel strike for each specific action. The velocities and accelerations will not be presented in this paper and are intended to verify the kinetic data obtained through the TekScan system. The angles were calculated using definitions provided by VICON who based the kinematic analysis from the works of Kadaba, Ramakrishnan & Wooten (1990) and Ounpuu, Tyburski & Gage (1991) (VICON Motion Systems 2016).

In instances where marker data was lost, gap filling was used to ensure kinematic results could still be obtained from each trial. Gap filling in VICON involves the researcher subjectively assigning a method to best interpolate the missing position data of a maker between frames (Camargo et al. 2020). The chosen methods in this study were the 'Pattern Fill' method, the 'Cyclic Fill' and the 'Spline Fill' method. Where only one marker of a segment was missing, the 'Pattern Fill' method was used as the software could recognise the motion of the remaining markers to interpolate the missing data. For actions where the motion was repeated, such as running, jumping or kicking, the ‘Cyclic Fill’ method was used as the software could use previous instances of the motion to estimate the missing position data. Finally, the ‘Spline Fill’ method was used when there was sufficient data either side of the gap, and a cubic spline function was used to interpolate the missing data (VICON Motion Systems 2016).

RESULTS: Kinematic results of male (n=3) and female (n=3) soccer players was collected in an outdoor environment on an artificial grass playing surface. The approach velocity was used as a metric to ensure both male and female players performed tasks with a similar intensity. Table 1 details the kinematic results for running based movements while Table 2 details movements that begin with a standing start. The values in each Table are the joint angles recorded at the ground contact for the support leg during each motion (i.e. the planted leg in a plant-and-cut, the stationary leg during kicking or the take-off leg during jumping). Positive joint angles are indicative of ankle inversion, dorsi flexion, knee extension, knee varus, internal tibial and hip rotation and hip adduction. Results for each individual and gender were averaged and the effect size, denoted by the Cohens D value, using SPSS 27.0 (IBM, New York, USA).

Table 1: Joint angles of male and female players at foot strike performing running based tasks.

	Running			***Run Stop***			***Run Turn***			***Plant-and-cut***		
Kinematic Data	*Male*	*Female*	*Cohen’s d*	*Male*	*Female*	*Cohen’s d*	*Male*	*Female*	*Cohen’s d*	*Male*	*Female*	*Cohen’s d*
Approach Velocity (m/s)	3.854	3.837	0.047	2.258	2.646	-1.089	2.011	2.254	-0.526	3.18	3.296	-0.218
Ankle												
Inversion/ Eversion (°)	1.8	-0.09	1.191	3.2	-1.3	0.893	-2.507	-0.3	-0.701	0.5	-1.1	0.554
dorsiflexion/ plantarflexion (°)	0.3	1.194	-0.105	-28.3	-24.0	-0.684	-4.466	-15.4	-0.841	0.5	-6.2	0.714
Knee												
Flexion/ Extension (°)	-0.5	-4.901	1.076	-12.9	-7.0	-1.105	1.4	-12.1	0.938	5.7	-6.3	0.996
Varus/ Valgus (°)	0.9	1.484	-0.118	3.7	1.7	0.410	16.3	1.0	1.136	-4.2	4.6	-0.877
Internal/ External Tibial Rotation (°)	-6.8	4.709	-1.349	-6.6	5.0	-2.056	4.6	4.1	0.055	-5.7	3.4	-0.997
Hip												
Internal/ External Rotation (°)	6.4	-2.2	1.382	5.6	2.7	1.159	-18.2	-3.3	-0.379	13.7	8.5	0.616
Abduction/ Adduction (°)	-10.8	-3.6	-0.871	3.8	1.5	0.209	9.8	0.5	0.838	15.2	12.6	0.271

Table 2: Joint angles of male and female players at ground contact of the supporting leg performing standing start tasks.

	Jumping			***Jump Exit***			***Side Foot Kicking***			***Instep Kicking***		
Kinematic Data	*Male*	*Female*	*Cohen’s d*	*Male*	*Female*	*Cohen’s d*	*Male*	*Female*	*Cohen’s d*	*Male*	*Female*	*Cohen’s d*
Ankle												
Inversion/ Eversion (°)	0.8	-0.3	0.218	0.7	-1.7	0.701	0.4	-0.8	1.558	-4.8	0.6	-1.812
Flexion/ Extension (°)	37.6	26.7	0.711	19.9	24.9	-0.558	-5.5	1.1	-1.086	-10.9	-2.6	-2.640
Knee												
Flexion/ Extension (°)	-17.4	-10.4	-1.046	1.7	-5.3	0.987	0.7	-6.1	0.376	-6.2	-8.6	0.203
Varus/ Valgus (°)	14.4	22.9	-0.514	-1.6	-18.0	2.169	6.3	10.4	-0.017	6.8	8.4	-0.257
Internal/ External Tibial Rotation (°)	4.5	16.2	-0.329	-2.8	1.7	-0.645	-0.6	13.1	-0.908	1.4	14.0	-1.231
Hip												
Internal/ External Rotation (°)	1.8	-1.6	0.273	1.6	-2.8	0.677	-3.0	-5.3	0.322	6.5	-9.0	2.206
Abduction/ Adduction (°)	11.0	12.4	-0.193	11.2	15.6	-0.930	5.1	1.5	0.435	-4.7	6.3	-1.952

DISCUSSION: From Cohen’s d values displayed in Tables 1 and 2, it can be deduced that while there were differences in ankle kinematics between male and female players, the larger differences were exhibited at the knee and hip. There were significant differences in knee angles, particularly in the movements that involved the player changing direction such as a plant-and-cut and the jump and exit manoeuvre. Female players tended to exhibit a larger valgus angle in these movements as well as a greater degree of external tibial rotation, as indicated by the Cohen’s d values which suggest a medium or large effect of gender on these angles. The increases in knee valgus and external tibial rotation have been shown to lead to an increase in load on the ACL (Ireland 1999). As this is a pilot study with a small sample population, these results provide indicative trends only, and a complete statistical analysis and testing with a larger sample size would produce more generalisable results. However, these initial findings prove promising at determining a link between the differences between male and female player kinematics and explaining the increase in ACL injury rate for female soccer players. Estimations of the knee loads obtained through the kinetic analysis of these movements is needed to indicate the likelihood of correlation between female kinematics and their increased rate of ACL injury. The joint angle data obtained in this pilot study exhibited similar patterns and results to previous studies that focussed solely on one movement. Hip abduction/adduction as well as ankle inversion/eversion followed a similar trend to those found in Landry et al. (2007), while knee varus/valgus and knee flexion/extension during a jump was similar to results obtained by Smith et al. (2007).

CONCLUSION: This paper describes a biomechanical analysis system that was used to collect 3D motion capture results as well as plantar pressure data that can be used to provide a kinematic description of soccer players on a pitch. Male and female players were recruited to complete specific movements often performed in a game on an artificial grass soccer pitch and joint angle data was used to compare the kinematic differences between them. Early analysis shows that female players exhibited higher values of knee valgus and external tibial rotation when performing change-of-direction tasks. These actions have previously been highlighted as potential risks for larger ACL loading and thus further biomechanical analysis will be undertaken to determine whether the movement patterns of female athletes are playing a part in their increased likelihood of injury.

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